

APPLICATION OF Cs-137 AND SOIL TRAPPING METHODS FOR STUDYING SLOPE PROCESSES IN THE CARPATHIAN FOOTHILLS¹

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ABSTRACT.- Areas of soil degradation and sedimentation have been delimited within a single, representative for the Carpathian Foothills, slope profile. Two methods: Cs-137 and soil trapping have been used. Soil degradation on the slope used as a pastureland is generally small, with the most intensive degradation in the midslope. Once the slope was cultivated the process of erosion and soil wash must have been more intensive which is evidenced by high Cs-137 content within the valley bottom deposits. High Cs-137 content within forested ecosystems results from good Cs-137 trapping efficiency of forests rather than from the soil deposition.

RESUMEN.- Aplicación del Cs-137 y de métodos de trapeo de suelo para estudiar procesos de ladera en el piedemonte de los Cárpatos. Se han delimitado las áreas afectadas por erosión y sedimentación en un perfil de ladera, representativo del piedemonte de los Cárpatos. Se han empleado dos métodos: Cesio-137 y trampas de sedimentos. Se ha demostrado que la erosión del suelo en laderas utilizadas para pastos es generalmente pequeña, apareciendo las degradaciones más intensas a media ladera. Cuando la ladera estaba cultivada, los procesos de erosión debían ser más intensos, como lo evidencia el alto contenido de Cs-137 en los depósitos de fondo de valle. El elevado contenido de Cs-137 en ecosistemas forestales se debe a la eficacia de los bosques para atrapar el Cs-137, más que a la sedimentación.

ZUSAMMENFASSUNG.- Anwendung der Cs-137 und der Fangmethode zur bestimmung der Hangvorgänge im Karpatenhügelland. Entlang eines Hangprofils innerhalb des Karpatenhügellandes sind Stellen ermittelt worden an denen, entweder Erosion oder Deposition festgestellt wurden. Das wurde aufgrund zweier Methoden bestimmt: anhand des radioaktiven Cs-137 und

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der Menge des erodierten Materials in eigens für diesen Zweck hergestellten Auffangbehältern. Es wurde festgestellt, dass auf einem als Weide genutzten Hang die Intensität der Erosion generell in seinem mittleren Teil am grössten ist. Als aber der untersuchte Weidehang als Ackerland genutzt wurde, war die Intensität der Erosion und Abspülung annehmbar bedeutend grösser, worauf die beachtliche Menge des Cs-137 in den Ablagerungen des Talbodens zeugt. Grosser Anteil des Cs-137 im Waldökosystem deutet auf eine erhebliche Aufnahmefähigkeit des Waldes der radioaktiven Niederschläge. Dieser Anteil resultiert nicht aus der Akkumulation des erodierten Materials.

Keywords: Cesium-137, Soil erosion, Sedimentation, Landuse effects, Carpathian Foothills.

Slope degradation can be examined by means of different methods. One of those uses Cs-137 redistribution in soils to assess the rate of this process and define areas of soil erosion and sedimentation (RITCHIE & MCHENRY, 1975). Another, more traditional method is soil-wash examination by means of trapping of soil particles in special troughs installed in the field (GERLACH, 1966). Both of them have been applied in the area monitored by the Institute of Geography Research Field Station in Łazy (Jagiellonian University, Cracow) situated on the edge of the Carpathian Foothills (Fig. 1).

Caesium-137 is an radioactive isotope which has appeared in the environment as a result of nuclear explosions since 1945. The intensity of radioactive fallout has depended on the character and magnitude of particular explosions. The first significant global fallout took place in 1952 (RITCHIE *et al.*, 1975). After 1963 the international control of nuclear energy caused a relative reduction in the fallout. The disaster of Chernobyl power-station in May 1986 resulted in a significant rise in radioactive contamination of the Earth's surface, especially in Europe.

After falling onto the Earth's surface Cs-137 is absorbed by soil mineral particles as well as organic matter (DAVIS, 1963). The migration of the isotope down the soil profile is insignificant because the isotope diffusion is very slow and it does not migrate with infiltrating water. This results in relatively high concentration of the isotope in superficial soil layers, whilst just a few centimeters down the profile Cs-137 concentration is low or even undetected. For these reasons Cs-137 can be used as a tracer in erosion and sediment studies.

In places undergoing an intensive soil erosion the isotope content within superficial layers is very low and becomes undetectable with depth. In places undergoing soil accumulation Cs-137 vertical redistribution is different. The formerly superficial layers containing much Cs-137 are then covered with the deposits eroded from slopes. This results in relatively high Cs-137 content even within deep layers of soil.

In case of ploughed soils Cs-137 vertical distribution is almost uniform due to mechanical mixing of soil particles and aggregates.

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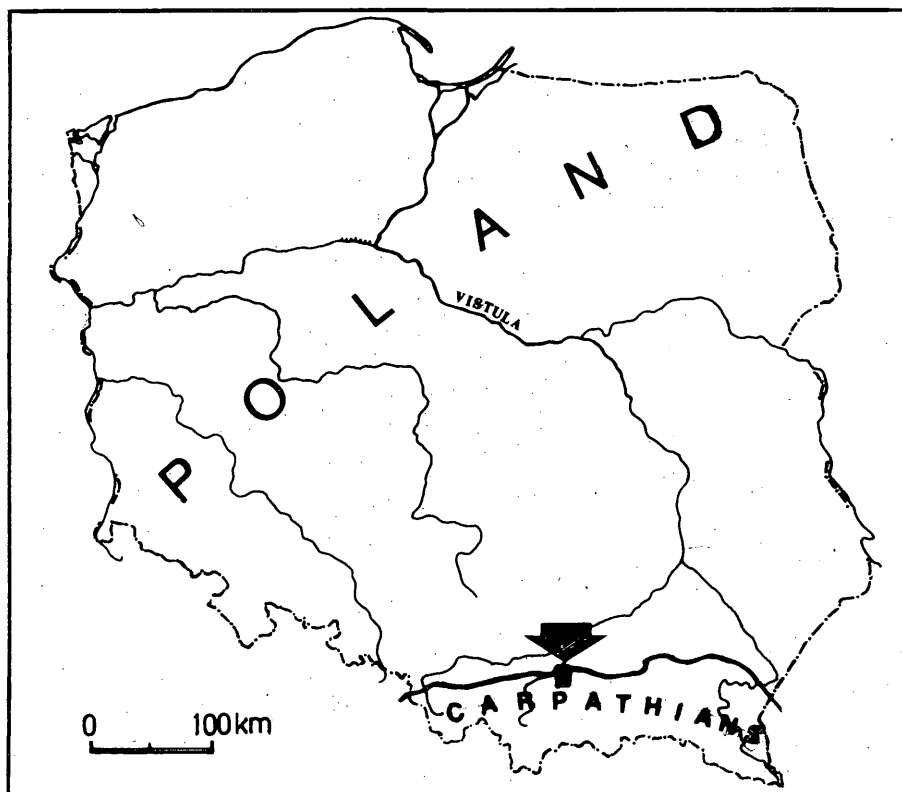


Fig. 1: Location of the study area. (*Localización del área de estudio*).

Different absorption ability of soils causes variations in areal distribution of Cs-137 content (WALLING, 1990). It was found (RITCHIE & MCHENRY, 1975; MCCALLAN *et al.*, 1980; CAMPBELL *et al.*, 1982), that Cs-137 is well absorbed by fine-grained soils, especially containing silt and clay particles. High content of the organic matter is also conducive to Cs-137 accumulation (MCHENRY & RITCHIE, 1977; RITCHIE & MCHENRY, 1978). Forests, can capture more Cs-137 from the atmosphere than open areas can. As we observe lack of or very small soil erosion on forested slopes it can be assumed that Cs-137 content within forest soils is equal or almost equal to the total fallout minus the amount resulting from the radioactive decay.

Soil particle trapping is a direct method of soil-wash measurements. Long-term and repeated sampling needs a lot of time and labour which puts the method into a disadvantageous position. On the other hand the results of the measurements are easier to interpret.

1. Aim of study

The study is a part of the project leading to a better understanding of slope process dynamics in the Carpathian Foothills, which have undergone extensive anthropogenic changes (SWIECHOWICZ, 1992). The aim of this study is to attempt to define within a single representative soil catena the sections undergoing soil erosion and those undergoing soil deposition. As two different methods (Cs-137 and soil trapping) have been involved it seems to be interesting whether the results obtained by means of these two methods confirm each other.

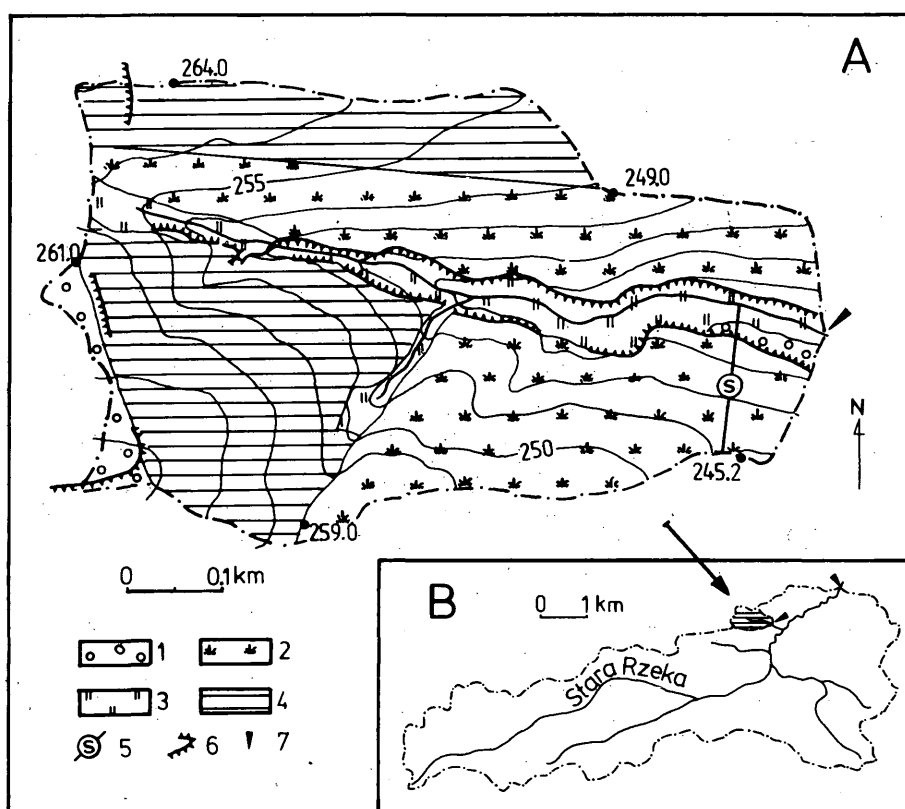


Fig. 2: Dworski Potok drainage basin (A) and its location within Stara Rzeki catchment (B). 1: forest; 2: pastureland; 3: hydrophilous meadow-type vegetation; 4: cultivated land; 5: examined profile; 6: slope edge; 7: stream gauge. (Cuenca de drenaje de Dworski Potok (A) y su localización dentro de la cuenca de Stara Rzeki (B). 1: bosque; 2: pastos; 3: prados hidrófilos; 4: tierras de cultivo; 5: perfil examinado; 6: límite de ladera; 7: aforo fluvial).

2. Study area

The study has been done in the Dworski Potok representative subdrainage basin (0.32 km²), which is a fragment of the Stara Rzeka catchment basin representing the northern margin of the Carpathian Foothills called *Pogorze Wisnickie* (SWIECHOWICZ, 1991, 1992) (Fig. 1 and 2). The Carpathian Foothills constitute in Poland about a 300 km. long and 25-50 km. wide belt of low hills rising up to 450 m a.s.l. Bedrock is made up of flysch deposits (sandstones, shales, slates and conglomerates) which dominate within the inner zone of the area. The outer zone being the geological edge of the Carpathians is built of intensively folded silt, loam and sand of Tortonian age. The bedrock of the Carpathian Foothills is covered with a very fine loess-like deposits. Agriculture is the main human activity there. Pasturelands, arable areas, orchards and meadows dominate in the landscape. Forests cover generally less than 20% of the area, however, locally the percentage of the forested lands is higher (30-35%).

The study has covered the slope profile (fig. 2A, photo 1) 133 m long, from the local water divide (245 m a.s.l.) to the bottom of the valley (231 m a.s.l.). The slope is convex-concave shaped and N-exposed. The angle of the



Photo 1: General view of the investigated slope (looking East). (*Perspectiva general de la ladera estudiada, mirando hacia el Este*).

upper part of the slope is 6.5°, whilst that of the lower part is 4.5°. The slope steeply (14°) changes into the valley bottom filled with both alluvia and deluvia being cut by the Dworski Potok channel. The mechanical composition of the deposits along the whole catena is almost uniform (Fig. 3), which is an important feature in Cs-137 studies. The slope is covered with pseudogley soils (*Stagnic Luvisols*) (SKIBA, 1992).

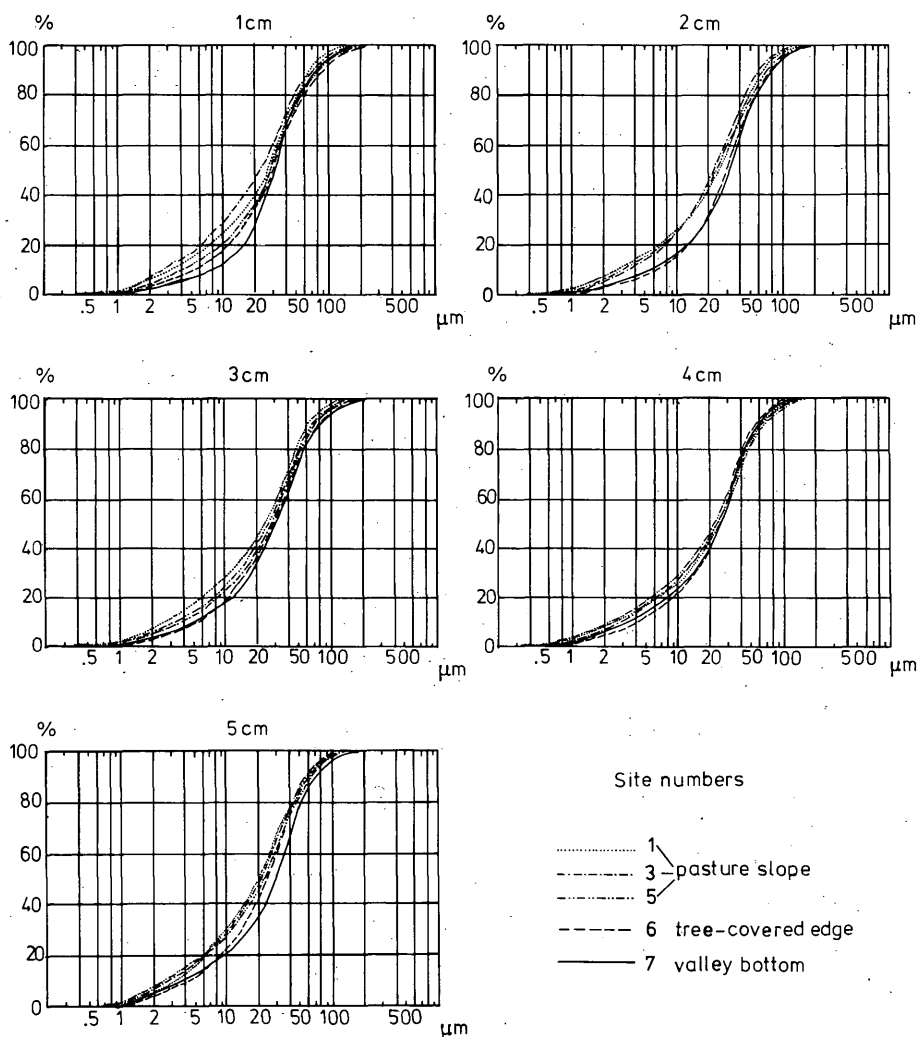


Fig. 3: Grain-size-distribution curves for top 5 cm of soil. (*Curvas granulométricas para los 5 primeros centímetros del suelo*).

Before 1970 all the slopes within the drainage basin were ploughed. Since 1970 the analyzed slope has been used as a pastureland for sheep (Foldcourse). By contrast to the slopes the bottom and the tree-covered edge have never been an arable land. In the bottom very-fine-grained warp soils (SKIBA, 1992) with meadow-type hydrophilous vegetation occur.

Methods of sampling

The soil samples for Cs-137 radiometric analysis were collected in May 1991 at 7 different sites within the whole catena (Fig. 4). Site n.º 1 was situated on the flat, grass-covered hilltop. Sites n.º 2, 3, 4, 5 were situated at 35, 58, 78 and 115 m. from the hilltop respectively; all of them within the pastureland (foldcourse). Site n.º 6 was situated 127 m. from the hilltop within the tree-covered edge and the site n.º 7 - 135 m. from the hilltop, within the bottom of the valley, about 0.5 above the bed of the Dworski Potok channel. At each site the grass was removed and then the soil samples were taken from 5 consecutive layers (one centimetre thick) within a square frame (30 x 30 cm.) each. All the samples came from planes parallel to the slope surface. The samples were dried (105° C), ridded of undecomposed organic litter, disaggregated in a mortar and sieved (1 mm. mesh). Cs-137 content was measured using Na-J detector and expressed in becquerels per kg. (Bq/kg).

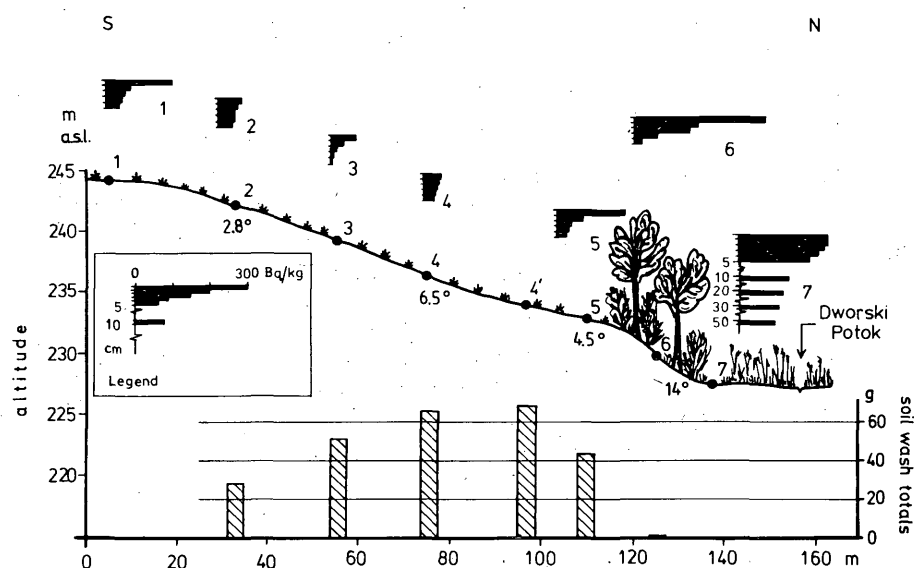


Fig. 4: Cs-137 depth profiles and soil-wash totals for July 1989-December 1990 at different sampling sites. (Perfiles de Cs-137 en profundidad y pérdidas totales de suelo para el período julio 1989-diciembre 1990 en diferentes puntos de muestreo).

After the first radiometric analysis, showing at site n.º 7 a very high Cs-137 content even for 5 cm. deep soil layer, the additional soil samples from the depth of 10, 20-21, 30-31 and 50-51 centimetres were taken.

Cs-137 sampling sites, except those numbered 1 and 7 were accompanied by previously installed (1989) modified Gerlach's troughs (photo 2) with an additional one numbered 4' between the sites n.º 4 and 5. The troughs (each of them 1 m. long) were installed parallel to the contours and connected with plastic containers for gathering run-off water and eroded soil particles. After each rainfall the samples were collected, then centrifuged, soil particles filtered, dried and weighted. For each site the total weight of the material caught has been calculated for the whole period of soil-wash measurements, grain-size analysis of the soil-samples has been done.

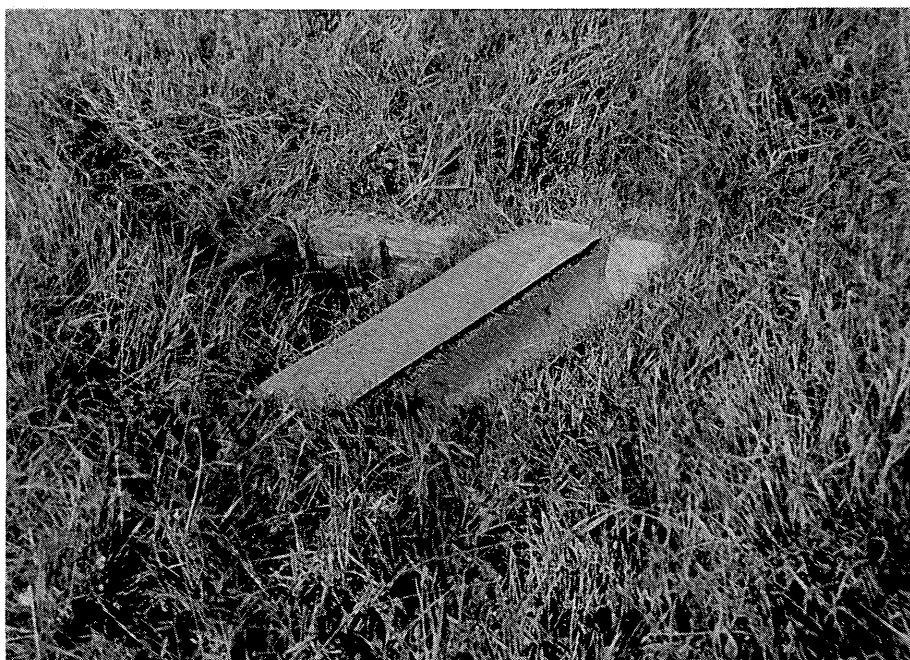


Photo 2: Modified Gerlach's trough for collecting soil-wash material. (*Caja Gerlach modificada para recoger suelo erosionado*).

Results

The Cs-137 content in the soil depends on the location and depth of the sampling site (tab. 1, fig. 4).

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TABLA 1

Cs-137 content in soil at different sampling sites in Bq/kg
(Contenido de Cs-137 en el suelo en diferentes puntos de muestreo).

Depth (cm)	Sampling sites						
	1	2	3	4	5	6	7
0-1	176.7	63.5	69.4	45.8	183.4	350.0	235.6
1-2	64.3	52.1	30.3	37.2	62.6	170.8	235.6
2-3	50.6	39.2	10.3	29.9	22.8	142.6	227.2
3-4	36.4	38.9	6.8	23.6	20.6	62.1	209.6
4-5	28.1	27.2	1.6	18.4	16.8	12.9	185.6
10-11	-	-	-	-	-	-	132.3
20-21	-	-	-	-	-	-	109.6
30-31	-	-	-	-	-	-	103.7
50-51	-	-	-	-	-	-	96.3

The error of Cs-137 estimation for all samples
varies between 11.9 and 15.0 per cent

As the current pastureland was, until 1970, arable, it can be assumed that the Cs-137 content within the soil profile was at that time uniform. Thus the vertical differences in Cs-137 content which we observe now may result from the slope processes taking place after 1970. This assumption does not apply to the tree-covered edge and the valley bottom.

Within the pasture the highest Cs-137 content was detected for both the hilltop and footslope sites. Between them, within the midslope, the Cs-137 content is significantly lower. This means that the most intensive soil erosion took place in the medium part of the slope.

The results discussed above are well supported by soil-wash measurements (fig. 4 - bars at the bottom). Generally the quantity of the trapped material is small. The largest amounts were measured for midslope troughs (sites n.º 3, 4 and 4'). The grain size analysis shows that the midslope superficial soil deposits are poorly sorted compared with the deposits of the other parts of the slope (tab. 2); this is the result of the partial removal of the finest soil particles. Thus Cs-137 content well correlates with the deposits sorting index (fig. 5).

If we assume that the soil layer from the midslope was eroded and then accumulated at the footslope we may expect there to be a higher Cs-137 content than at the hilltop. However, this is not the case. Cs-137 content at both footslope and hilltop sites is almost the same, indicating that the midslope material must have been deposited somewhere away the footslope, at the tree-covered edge.

Within the tree-covered edge (site n.º 6), Cs-137 content, in the top 1 cm. of soil, is high. On the other hand the total amount of the trapped material is extremely small. This shows almost insignificant soil-wash there and suggests

TABLA 2

Sorting index (So) for top 1 cm. of soil
(Índice de clasificación para el primer centímetro del suelo).

Site number

1	2	3	4	5	6	7
4,83	4,92	5,22	5,47	4,47	3,74	3,27

$$So = \sqrt{\frac{d_{90}}{d_{10}}}$$

that the eroded material must have been deposited somewhere between sites n.º 5 and 6, probably at the border between pastureland and the tree-covered area, where no sampling was done. The reason for the high Cs-137 content inside the forested area seems to be the great trapping efficiency of the tree ecosystem compared with the grass one situated above.

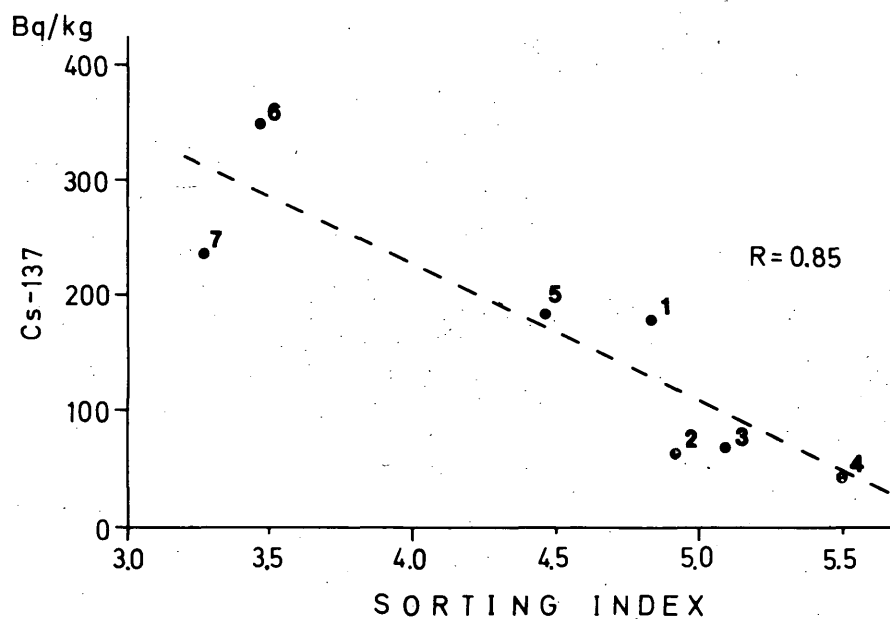


Fig. 5: Relationship between Cs-137 content and sorting index for top 1 cm. layer of soil (The lower index, the better sorting). (Relaciones entre el contenido de Cs-137 y el índice de clasificación para el primer centímetro del suelo. Cuanto más bajo es el índice, mejor clasificación)

The valley bottom soils (site n.º 7) contain more Cs-137 than any other soil within the basin. Moreover, in contrast to the slopes, the high Cs-137 content at the bottom is detected even for 50 cm. deep soil layer. This is the evidence for abundant soil deposition there. As generally the intensity of the soil-wash in pastureland seems to be quite small; it looks as if the valley bottom deposits must have been delivered there before 1970, when the majority of the basin slopes were under cultivation. The source of the material deposited within the valley bottom were these slopes which were not separated from the bottom by the tree-covered belt. Recently only about 32 per cent of the basin has been arable land and the extent of soil erosion is significantly lower than 22 years ago. Another factor contributing to the high Cs-137 content within the valley bottom sediments can be soil organic matter originating from the abundant hydrophilous vegetation; however, this must be confirmed by additional studies.

Conclusions

The analysis of the Cs-137 content shows that the mid-slope undergoes more intensive slope-wash degradation than any other of its parts. At the hilltop the erosional processes do not play a significant role or they do not exist at all (*belt of no erosion*—according to HORTON, 1945). Previously, before 1970, the intensity of erosional processes must have been greater. The deposition of the slope material took place at the valley bottom and resulted in high Cs-137 content even for deep soil horizons. Relatively high Cs-137 content at the tree-covered edge may result from the great trapping ability of forests. The results obtained by means of two different methods (Cs-137 and soil trapping) support each other.

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References

- CAMPBELL, B. L., LOUGHRAN, R. J. & ELLIOT, G. L. (1982): Caesium-137 as an indicator of geomorphic processes in a drainage basin system, *Australian Geographical Studies*, 20: 49-64.
- DAVIS, J. J. (1963): Caesium and its relationship to potassium in ecology. In *Radioecology*, pp. 539-556, Reinhold, New York.
- GERLACH, T. (1966): Współczesny rozwój stoków w dorzeczu górnego Grajcarek (Beskid Wysoki) (Recent development of slopes in the upper Grajcarek drainage basin), *Prace Geogr. IG PAN*, 52: 1-124.

- HORTON, R. (1945): Erosional development of streams and their drainage basins, *Bull. Geol. Soc. Am.*, 56: 275-370.
- MCCALLAN, M. E., O'LEARY, B. M. & ROSE, C. W (1980): Redistribution of Caesium-137 by erosion and deposition on an Australian soil, *Australian Journ. of Soil Res.*, 18: 119-129.
- McHENRY, J. R., RITCHIE, J. C. & GILL, A. C. (1973): Accumulation of fallout caesium-137 in soils and sediments in selected watersheds, *Water Resour. Res.*, 9: 676-686.
- McHENRY, J. R. & RITCHIE, J. C. (1977): Physical and chemical parameters affecting transport of Cs-137 in arid watersheds, *Water Resources Research*, 13: 923-927.
- RITCHIE, J. C. & McHENRY, J. R. (1975): Fallout Cs-137: A tool in conservation research, *Journ. of Soil and Water Conservation*, 30, 6: 283-286.
- RITCHIE, J. C. & McHENRY, J. R. (1978): Fallout caesium-137 in cultivated and non cultivated North-Central United States watersheds, *Journ Environ. Quality*, 7: 40-44.
- SKIBA, S. (1992): Gleby zlewni Starej Rzeki na Pogórzu Wielickim (Soils of the Stara Rzek drainage basin at the Wieliczka Foothills), *Zesz. Nauk UJ, Prace Geogr.*, 88: 39-47.
- SWIECHOWICZ, J. (1991): Budowa geologiczna i rzeźba zlewni Starej Rzeki (Geological structure and landforms of the Stara Rzek drainage basin), *Zesz. Nauk. UJ, Prace Geogr.*, 83: 165-184.
- SWIECHOWICZ, J. (1992): Naturalne i antropogeniczne uwarunkowania przebiegu denudacji zlewni Starej Rzeki (Natural and anthropogenic conditions of denudation processes in the Stara Rzek drainage basin), *Zesz. Nauk. UJ. Pr. Geogr.*, 88: 49-69.
- WALLING, D. E. (1990): Monitoring contemporary geomorphological processes, [in:] A. Breymeyer (ed.), *Global Change Regional Research Centres: Scientific Problems and Concept Development. Seminar Papers, and IGPB WG2 REPORT, Inst. of Geogr. and Spatial Organization, Pol. Acad. Sci., Conference Papers*, 6: 7-32.